## RELIABILITY, MAINTAINABILITY AND AVAILABILITY (RAM)

## I. DEFINITIONS

**Reliability:**

probability of satisfactory performance during a *given period* under *specified operation conditions*.

**Maintainability:**

defined as a characteristic in design that can be expressed in terms of maintenance frequency factors, maintenance times and maintenance cost. (MTBM, MTBF, ....) Maintainability is the ***ability* of an item to be maintained.** Maintainability is an inherent characteristic of system or product design. **Maintenance** constitutes a series of actions to be taken to restore or retain an item in an effective operational state. Also see, corrective (unscheduled) and preventive (scheduled) maintenance, and levels of maintenance (O, I, D-level).

**Maintainability Factors:**

*Mean Time Between Maintenance: MTBM*

*Mean Time Between Failures:* $MTBF = 1/\lambda$

*Mean Time Between Replacement: MTBR*

*Mean Corrective Maintenance Time:* $\overline{M}ct$

*Mean Preventive Maintenance Time:* $\overline{M}pt$

*Mean Active Maintenance Time:* $\overline{M} = \dfrac{(\lambda)(\overline{M}ct)+(fpt)(\overline{M}pt)}{\lambda + fpt}$ where $fpt$ $(= 1/MTBM_s)$ is the frequency of the preventive maintenance actions per system operating hour (preventive maintenance rate).

*Meantime Between Maintenance:* $MTBM = \dfrac{1}{\dfrac{1}{MTBM_u} + \dfrac{1}{MTBM_s}} = \dfrac{1}{\lambda + fpt}$

where $MTBM_u$ (same as MTBF) is the mean interval of unscheduled (corrective) maintenance and $MTBM_s$ is the mean interval of scheduled (preventive) maintenance.

***Logistic Delay Time (LDT)*** is the maintenance downtime that is expended as a result of waiting for a spare part to become available, etc. Does not include active maintenance time.

***Administrative Delay Time (ADT)*** is the portion of downtime during which maintenance is delayed for reasons of an administrative nature. Does not include active maintenance time.

***Maintenance Downtime (MDT)*** is the total elapsed time required to repair and restore a system to full operating status. It includes mean active maintenance ( $\overline{M}$ ), logistics delay time (*LDT*) and administrative delay time (*ADT*).

**Availability:**

the measure of the degree a system is in the operable state at the start of a mission when the mission is called for at an unknown random point in time (usually steady state readiness measure) under the actual operating environment.

**Inherent Availability ($A_i$):** $A_i = \dfrac{MTBF}{MTBF + \overline{M}ct}$

Probability that a system or equipment, when used under stated conditions in an *ideal* support environment, will operate satisfactorily at any point in time as required.

**Achieved Availability ($A_a$)**: $A_a = \dfrac{MTBM}{MTBM + \overline{M}}$

Similar to $A_i$ except that preventive maintenance is included. It excludes LDT and ADT.

**Operational Availability ($A_o$)**: $A_o = \dfrac{MTBM}{MTBM + MDT}$

Probability that a system or equipment, when used under stated conditions in an *actual* operational environment, will operate satisfactorily when called upon. The operational availability a commonly-used readiness measure for weapon systems. This value provides the percentage of a weapon system that is in MC (mission capable) status. Thus we can rewrite: *operational availability = number of MC /total number.*

EX: *USS Independence* has one F/A-18 squadron that has 12 aircraft. The MTBM of each aircraft is 200 hours and MDT is 50 hours. Find the probability that all 12 F/A-18's are ready to fly tomorrow morning 0600.

## II. RELIABILITY

Let *T* be a random variable that represents the time until next failure (or the time between failures), and *f(t)* be the probability density function (p.d.f.) , and *F(x)* is the cumulative density function (c.d.f) of *T*. Then the reliability function, *R(t)*, is defined as
*R(t)* is the probability that the failure will not occur until time t.

$$R(t) = Pr(T > t) = \int_t^{\infty} f(x)dx = 1 - F(x)$$

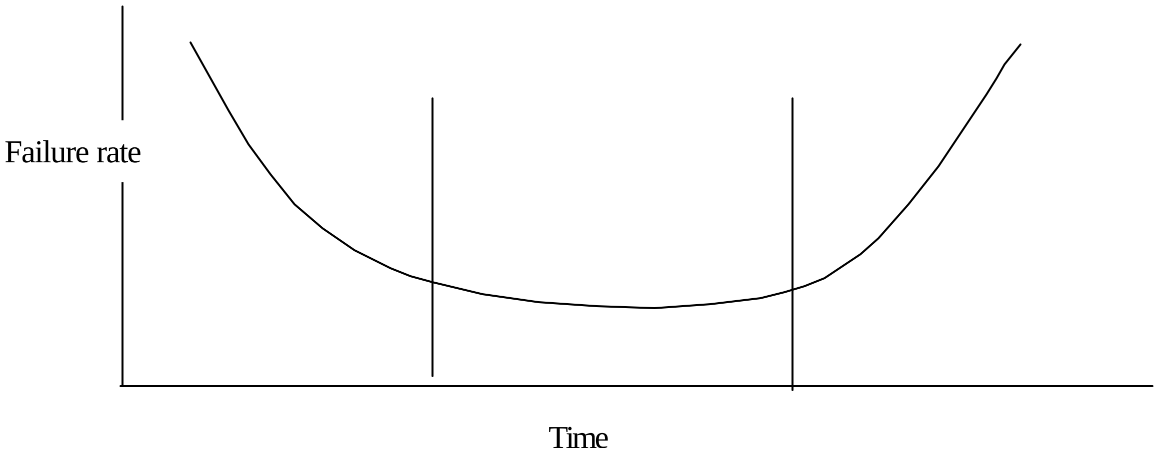
If *T* is an exponential random variable, the reliability function *R(t)* is

$$R(t) = Pr(T > t) = \int_t^{\infty} f(x)dx = \int_t^{\infty} \lambda e^{-\lambda x} dx = e^{-\lambda t}$$

Example: A component has T- Exp ($\lambda$) with $\lambda$ = 0.03 failures / hr, or MTBF = $1/\lambda$

(A) Pr (the component will still run after 10 hours) = R(10) = $e^{-0.03\,(10)}$ = 0.7408

(B) Pr(T>200) = R(200) = $e^{-0.03(200)}$ = 0.0024788




**Bathtub curve for mechanical vs electronic component?**

**Reliability network**

Series network

Parallel network

Combined series-parallel network

**Exercise Problems**

1. Three F/A-18's, A, B, C are sent to bomb a certain target. Each plane is to drop one bomb. The probabilities of a plane's bomb hitting the target are 0.6, 0.5, 0.3 for planes A, B, C respectively. Assuming independence, find the probability that the target is (a) hit at least once and (b) not hit at all.

2. (a) A hunter confronts a charging rhinoceros. He has a rifle and the time to fire three rounds. The probability of a hit on the first round is $p_1$. If the first round is a miss, the probability of a hit on the second round is $p_2$. If the first two rounds are misses, the probability of a hit on the third round is $p_3$. Find the probability that the rhinoceros is hit.

   (b) Three hunters confront a charging rhinoceros. Each has a rifle and will fire one round. The probability that the first hunter hits is $p_1$. The probability that the second hunter hits is $p_2$. The probability that the third hunter hits is $p_3$. Find the probability that the rhinoceros is hit.

   (c) Which group of hunters would a stochastically sophisticated rhinoceros prefer to charge?

3. The time to failure of a certain electronic component in a radar system follows the exponential distribution with a mean of 300 hours.

   (a) Find the probability that the component will not fail during the first 200 hours.

   $T \sim \text{Exp}(\lambda)$ where $\lambda = 1/300$
   $R(200) = \exp(-200\lambda) = 0.5134$

   (b) How many components should be used in parallel to achieve the failure rate during the 200 hour operation less than 0.01?

   We need to find the minimum n (integer value) such that
   $R_{sys} = 1 - (1 - r)^n \geq 0.99$, where $r = .5134$
   $1 - (1 - 5134)^n = 1 - 0.4866^n \geq 0.99$

$$n \geq \frac{\ln 0.01}{\ln 0.4866} \approx 6.39$$

4. A total of five F/A-18's have been assigned to fly from *USS Nimitz* to Kosovo for a highly classified mission. Each aircraft has two engines, and the time between engine failures (including combat damage) is exponentially distributed with an MTBF of 100 hrs. The mission duration is estimated to be 5 hours. To make the problem simple, we'll assume that each engine operates independently. If both engines fail, the pilot has been instructed to abandon the aircraft. Otherwise, we'll assume that the aircraft can safely return to *Nimitz*. Find the probability all 5 aircraft will safely return to *Nimitz*.

5. A tactical UAV(unmanned aerial vehicle) system consists of a ground control station, data terminal and several air vehicles. An air vehicle (AV) consists of an engine, a propeller and a navigation computer. If the ground control station and/or data terminal fail(s), the AV will return using the preprogrammed navigation computer. Loss of both guidance systems (i.e., one or both) of control station and data terminal, **and** the navigation computer) at the same time will cause a loss of an AV. An engine or propeller failure will cause a loss of an AV. The MTBF of each subsystem is specified below. Assume that each component operates independently. Calculate the probability of loss of an AV during a 10-hr mission.